CLOUDSAT: A SPACECRAFT TO MEASURE Till? VERTICAL STRUCTURE OF CLOUDS

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ABSTRACT

CloudSat is being developed to measure the vertical structure of clouds from space. It integrates a 94-GHz cloud profiling radar (CPR) with an A-band spectrometer/visible imager (ABSI) and a submillimeter-wave cloud ice radiometer (CLIR). CPR maps vertical cloud profiles with 500 meter resolution. ABSI detects very thin clouds and images the regional cloud field. CLIR retrieves cirrus ice content and crystal size. Cloud Sat is designed to provide data to improve how clouds and cloud-feedbacks are parameterized in general circulation models (GCMs). It will also demonstrate the utility of space-based cloud profiling for future forecast systems.

INTROD1JCTION

CloudSat is a space-based approach to measure the vertical structure of clouds. This mission is being designed to investigate how clouds affect climate. Existing models relating cloudiness, atmospheric circulation, and temperature lack the accuracy needed to meet climate modeling needs. Current and planned observation systems are unable to probe the structure of multi layer clouds which are key to deciphering a range of climate feedback mechanisms. CloudSat is uniquely suited to resolve the mechanisms interrelating climate and clouds.

The original CloudSat mission concept was developed for the cost-constrained NASA Earth System Science Pathfinder (ESSP) mission series. The proposed payload consists of a 94-GHz cloud profiling radar (CPR), an oxygen A-band infrared spectrometer integrated with a visible imager (A BSI), and a submillimeter-wave cloud ice radiometer (CLIR) as show in Figure 1. This payload will be able to determine the vertical distribution clouds, measure cloud optical depth, retrieve cirrus ice content, and assist in validating measurements made by the NASA Earth Observing System (EOS). CloudSat will also furnish an important technology demonstration for future scientific, civilian, and tactical forecast systems.

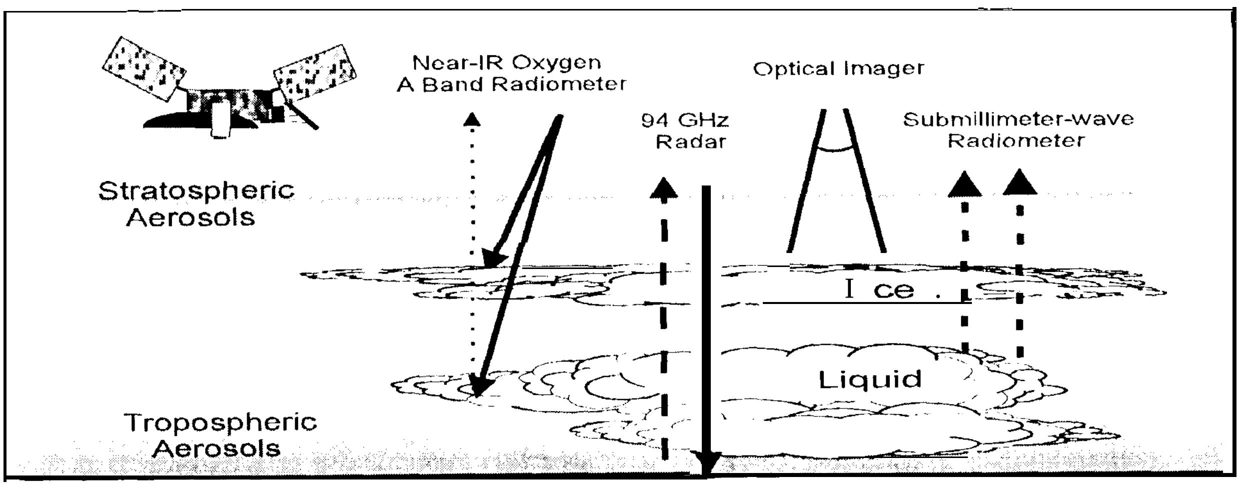

***Figure** 1. The CloudSat payload will measure the vertical structure of clouds to study the impact that clouds have on climate using a 94-GHz radar, IR spectrometer, submillimeter-wave radiometer, and optical imager.*

2. MISSION OBJECTIVES

CloudSat was conceived to investigate the effect of clouds on radiative heating of the atmosphere. It is designed to compile a database of cloud measurements to be used to identify and quantify fundamental climatic processes relating the earth's energy balance to its hydrological cycle. The ultimate goal is improve the accuracy of climate models by developing more realistic representations of clouds and their influence on climate.

The greenhouse effect determines the global energy balance. When the earth is in equilibrium, the amount of solar energy illuminating the earth equals the amount of energy being radiated back to space. Solar energy incident at the top of the atmosphere is scattered, absorbed, and transmitted by clouds, aerosols, and atmospheric gases. Roughly 30% of the radiation is scattered directly back to space, while the rest of the radiation warms the soil, oceans, and atmosphere. As the earth surface warms it radiates infrared or thermal energy to space. The amount of energy radiated to space increases with temperature. When the incident solar energy is balanced by the reflected solar energy and the thermal emissions, the planet is in equilibrium. Central to calculating the equilibrium state are greenhouse gases which are transparent to visible light and absorb infrared light. Gases such as water vapor and carbon dioxide let visible light warm the surface while trapping thermal emissions. Hence, an increase in greenhouse gas concentration increases the earth's temperature. The uncertainty in predictions of greenhouse warming lies in the ability to accurately model feedbacks in the land-ocean-atmosphere system.

g'here are significant uncertainties in the feedbacks that occur between the hydrological cycle and the earth energy balance due to the coupling between temperature, circulation, and hydrology (i. e., clouds, precipitation, and distribution of water vapor). For example, the formation of clouds will modify the temperature structure of the atmosphere. A change in temperature then affects atmospheric circulation. In turn, variations in atmospheric circulation will modify the hydrological cycle. Accurate modeling of the interrelationships between these element is necessary to derive the response of the earth to a perturbation such as an increase in carbon dioxide.

Understanding and resolving climate feedback mechanisms is an important objective for the NASA EOS mission set. However, planned *EOS*, GOES, and NPOESS payloads will not be able to detect the presence of multilayer clouds reliably. They arc therefore limited in their ability to characterize cloud-induced beating of the atmosphere which is essential to elucidate cloud-climate feedbacks. It is this observational gap that CloudSat intends to fill. The design for CloudSat will provide ncw insight into climatic processes by:

- Documenting the vertical distribution of cloud systems with 250 to 500 meter resolution.
- Measuring the total cirrus icc content and vertical distribution of ice water to 300/o.
- Providing new measurements of optical depth and cloud phase by retrieving the asymmetry parameter.
- Validating EOS cloud and radiative flux products.
- integrating CloudSat and EOS observations to assess the performance of climate models at simulating atmospheric heating.

3. SCIENCE PAYLOAD

3.1 CLOUD PROFILING RADAR (CPR)

The CloudSat radar, CPR, determines the cloud profile. It operates at 94-GHz using 1.5 kW peak transmit power, a repetition rate of 4700 Hz, and an recoded pulse width of 3.3 μs. The radar footprint is roughly 900 meters requiring an antenna diameter of 1.85 meters. The antenna, a center-fed Cassegrain, requires that spacecraft be pointed with an accuracy of 0.5° to minimize direct surface reflections and contamination from sidelobes. The power, mass, dimensions, and data rate for the CloudSat payload arc summarized in 'Table 1.

The choice of radar frequencies is a trade-off between sensitivity, technological limits, and atmospheric attenuation. Radar backscatter from hydrometeors (ice crystals, cloud droplets, and precipitation) increases dramatically with increasing frequency. This needs to be balanced against atmospheric transmittance and the performance of radar technology which both degrade at higher frequencies. The choice of 94 GHz means that a small percentage of the time when very thick clouds or heavy precipitation is present, the radar will not be able to penetrate the cloud base. The mission objective dictates this choice: to derive radiative heating, it is more important to be able to detect thin high clouds than it is to determine the base of a heavy cloud deck.

The radar has been designed with pulse coding capability to enhance sensitivity to mid to high-level thin clouds. When pulse coding is selected the radar transmits 33.3 μs pulses at a 9001 Iz repetition rate. Pulse coding increases sensitivity at the expense of generating range sidelobes from the surface and highly reflective clouds. The range sidelobes associated with the earth surface will obscure clouds near tbc ground. Thus, it is envisioned that coded pulses will be interspersed with uncoded pulses in order to resolve botb th in clouds and surface-level clouds. The sensitivity of tbc radar is projected to be -32 dBZ for uncoded pulses and -38 dBZ for coded pulses.

TABLE 1. PAYLOAD RESOURCE SUMMARY

Instrument	Mass	Avg. Power	Length	Width	Height	Data Rate
CPR Antenna	21.6		1.85 (diam.)	1.85 (diam.)	.27	
(I'R Electronics	69.1	209-266†	0.3	0.7	0.3	<15
ABSI	15.0	12	0.45	0.25	0.45	110
CLIR Antenna	5.9		1.0 (diam.)	1.0 (diam.)	0.75	
CLIR Electronics	24.2	26	0.45	0.3	0.2	< 3
Contingency	**20%**	**20%**				
Total	163	318†				

'Range in power requirements is due to difference in power required for coded pulses vs. uncoded pulse operation. The total assumes use of uncoded pulses 70% of the time.

3.2 OXYGEN A-BAND SPECTROMETER AND VISIBLE IMAGER (ABSI)

ABSI is a high resolution spectrometer centered on the oxygen A-band (-770 nm) integrated with a visible imager. The spectrometer/imager will provide the capability of detecting thin clouds anti aerosol layers, provide a coarse estimate of their altitude, determine optical depth, and document the morphology of the cloud field. With a signal-to-noise of 1000:1 it will be able to measure an optical depth of 0.02 with 3% accuracy. ABSI will oniy operate during the daytime became the spectrometer and imager require sunlight.

The visible imager (748 nm ± 5 rim), provides the context for CloudSat measurements. It will allow researchers to associate cloud profiles with mesoscale weather patterns. For example it will be able to identify when a cloud profile is associated with a tropical storm, a cumulus column, or a uniform cloud deck. The data from the imager will be highly compressed to reduce its data requirements.

The high resolution spectrometer determines the optical depth and altitude of thin clouds by making high spectral resolution (0.5 cm^{-1}) measurements at the oxygen A-band (761 nm -772 rim). The oxygen A-band is characterized by a "thicket" of closely spaced spectral lines. Therefore a small change in wavelength will vary the rate at which light is attenuated as it traverses the atmosphere. With measurements made at a wide range of attenuation lengths, it is possible to determine optical depth, photon path length, characteristics of the scattering particle, and its altitude.

3.3 CLOUD ICE RADIOMETER (CLIR)

Submiiiimeter-wave radiometric measurement of cloud ice is a new technique for retrieving cirrus ice mass and ice crystal size. It can be understood intuitively. in the absence of clouds, the earth appears to emit a relatively uniform background of submillimeter-wave (> 300 GHz) radiation emitted by mid-tropospheric water vapor. When viewed from space, cirrus clouds will scatter the background emissions back toward the earth reducing the upward flux of submillimeter-wave energy. Hence, cirrus clouds appear "cool" against the "warm" emission background. The reduction in radiative brightness is dependent on both the number of ice crystals and their sizes. Measurements made at two widely separated frequencies permit variations in thermal flux caused by changes in mean crystal size to be distinguished from changes in ice content.

The CloudSat radiometer is a sensitive heterodyne receiver tuned to 640 GHz and 183 GHz. When coupled with 94 GHz radar measurements, the 640 GHz measurements of atmospheric brightness allows retrieval of ice mass and mean crystal size. Since 183 GHz is situated on a water vapor line it can yield a similar atmospheric opacity as is observed at 640 GHz. However, it has virtually no sensitivity to cloud ice, therefore the measurement at 183 GHz provides an independent measure of variations in the water vapor emission background ensuring that structure in the background doesn't contaminate the retrievals of ice mass and crystal size.

The Cloud Ice Radiometer (CLIR) receivers will utilize planar-Schottky mixers feeding an IF bandwidth of 1.5 GHz. The receiver will have 0.5 K sensitivity and will be calibrated to better than 1 K accuracy using a cold sky view and an "ambient" target. The radiometer footprint is matched to the radar requiring a 1 meter diameter antenna utilizing a 10 cm secondary illuminated by an offset feed.

4. SPACECRAFT REQUIREMENTS

The mission was designed for a lifetime goal of two years to enable more than one seasonal cycle to be observed. The desired orbit is a nearly sun-synchronous orbit (altitude = ~ 475 km, inclination = 97,1") providing coverage to 83° latitude. Communications is accomplished via an S-band transceiver using an omni-directional antenna and X-band transmitter for data downlink utilizing a helical antenna. Independent calibration of the instrument payload will take advantage of ground-based observational sites such as the DOE Cloud and Radiation Testbeds, NASA airborne science campaigns, and university research facilities worldwide. The total weight of the commercial spacecraft was estimated to be approximately 600 kg requiring an average of 550 W of power. However, since no teaming arrangements have been formalized for future proposals opportunities, it would be inappropriate to identify the original spacecraft manufacturer or reveal proprietary information about their spacecraft bus.

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The CloudSat concept was originally proposed for the first NASA ESSP mission opportunity. It was ranked very highly, but was not selected due to the ESSP program cost cap. We plan to propose this mission concept to the 1998 ESSP Announcement of Opportunity which may adopt a higher cost cap. The science team is currently exploring the possibility of teaming with international partners and other government agencies that have related interests to facilitate cost-sharing improving the overall competitiveness of the proposal.

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